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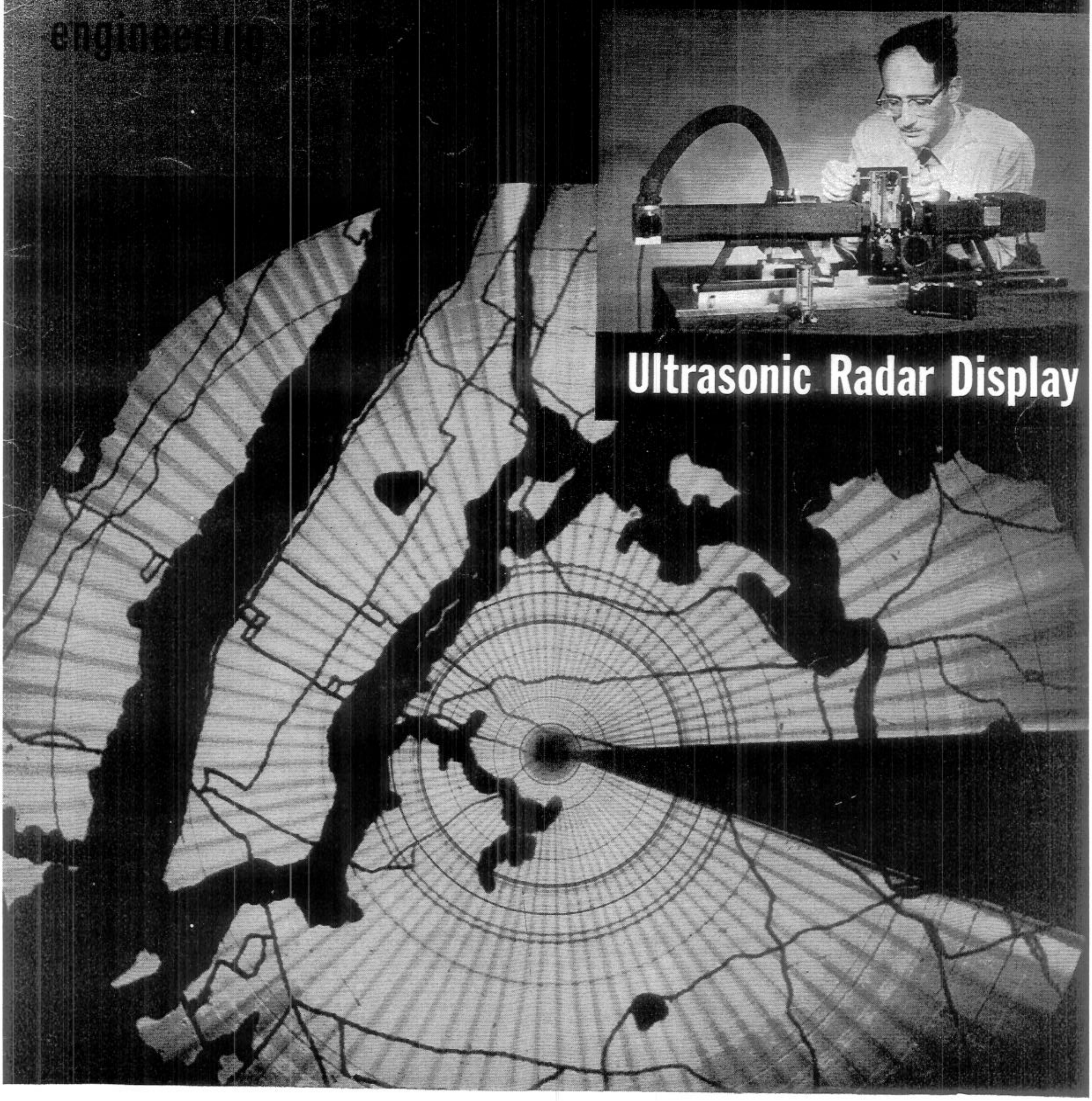

Ultrasonic Radar Display

WESCON PROGRAM and SHOW GUIDE

Light Modulator Records Airborne Radar Displays

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Light Modulator Records

Light modulation using an ultrasonic cell achieves resolution and dynamic ranges previously unattainable. For applications in video recording and radar strip-mapping, resolution of the device is limited only by the optical system and photographic material. Additional data can be displayed in color

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LIGHT MODULATION is not a new technique. The development of wirephotos and soundtracks on movie films have considerably advanced this technique. With the advent of television and radar however, problems of new proportions have resulted Whereas earlier work involved light modulation at audio frequencies, it now is necessary to convert signals in the megacycle range into visible form.

One successful light modulation device is the cathode ray tube. Because of the relative facility of scanning an electron beam, the crt is simple and flexible. Unfortunately, a crt display suffers from limited resolution and low dynamic range. Low resolution is caused by limitations in focusing the electron beam. In practice it is not possible to obtain much more than 1,000 elements across a tube diameter with any appreciable contrast.

The limitation in dynamic range is a result of the halation effect which accompanies a crt display. Dynamic range is defined as the ratio of the maximum signal displayed to the minimum signal observable. If low light intensity is measured on a spot of the crt display, it cannot be learned for certain if there actually is a low intensity beam impinging on this spot or if the halation effects from an adjacent bright spot are illuminating it. In practice the dynamic range of the cathode ray tube is limited to approximately 15 to 1.

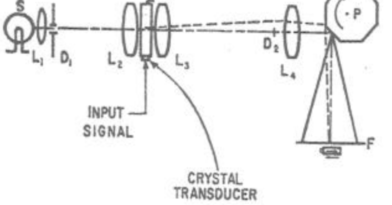


FIG. 1—Ultrasonic cell produces intensity-modulated image at surface *F*

Ultrasonic Cell

Ultrasonic light modulation overcomes the basic crt deficiencies outlined above. Its operation is based on the diffraction of light at ultrasonic wave fronts. The heart of the system is the ultrasonic cell, which consists essentially of a liquid medium in contact with a piezoelectric transducer. This transducer has the property of expanding or contracting when a potential is applied across it. When an alternating potential is applied, it vibrates, sending pressure waves down the column of liquid in contact with it. These pressure waves produce periodic variations in the refractive index of the liquid.

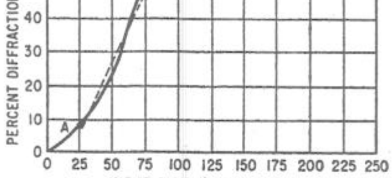


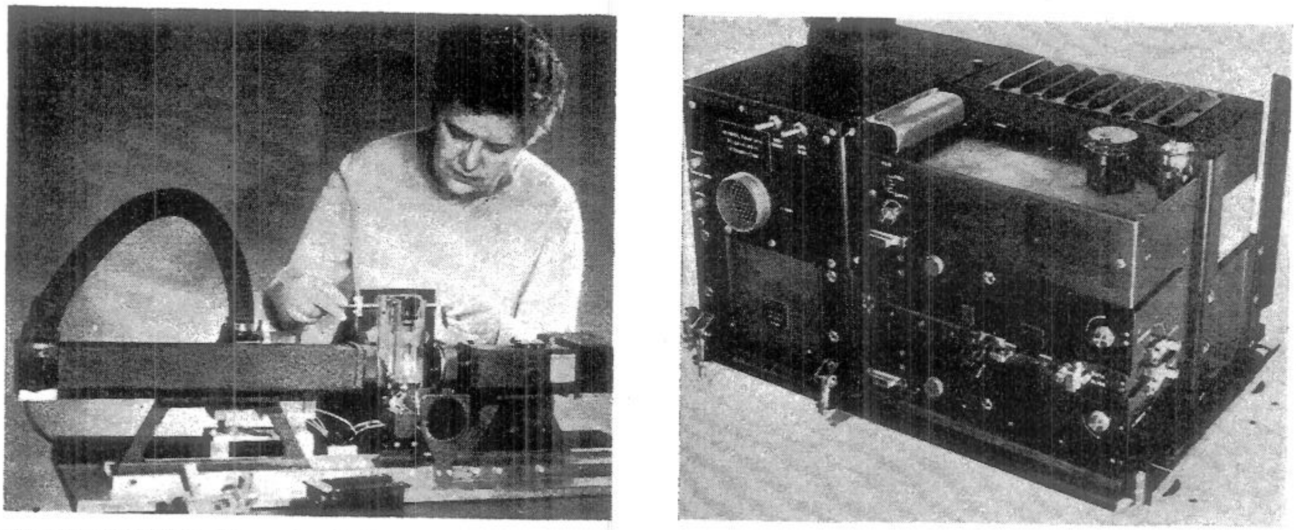
FIG. 2—Diffraction efficency plotted as a function of input signal amplitude

Diffraction Grating

The portions of the incident light wave which pass through pressure peaks are retarded and those passing through the pressure troughs are advanced in phase. As a result, a plane wave front entering the ultrasonic cell leaves it as a corrugated wave front producing a diffraction grating effect.

The operation of the system is illustrated by the optical schematic shown in Fig. 1. A slit in diaphragm D_1 is illuminated by the source S through condensing lens L_1. An image of the slit is formed on an opaque bar at D_2 by lenses L_2 and L_3. The bar at D_2 is slightly larger than the image of D_1 so that it stops all the light entering the system at D_1. The ultrasonic cell is placed in the collimated region between L_2 and L_3. Lens L_4 forms an image of the ultrasonic cell in the plane F after reflection from mirror P. Under the circumstances just described, the image at F will appear completely dark since none of the light illuminating the cell can pass D_2. When a signal is applied to the ultrasonic cell, light is diffracted around the stop D_2, as indicated by the dotted line. Light now passes D_2 and as a result the image

Airborne Radar Displays



THE FRONT COVER—Ultrasonic cell shown being adjusted at left is the heart of radar airborne strip-map recorder at right. High resolution, dynamic range, and linearity as well as its ability to vary the color of the recorded image make recorder versatile and flexible

at surface F becomes bright.

If a short burst of carrier wave is applied to the transducer, a train of pressure waves travels down the ultrasonic cell. At F this appears as a bright spot traveling the length of the cell image with the velocity of sound in the cell medium, as indicated by the arrow in the cell image at F. To record this spot of light, either a short exposure may be used or the spot may be made to stand still by rotating the reflector P. A rotation of the reflector in the sense indicated in the diagram makes the cell image move in the direction indicated by the arrow at F. If the velocity of image motion is equal and opposite to the velocity of the pulse inside the cell, the pulse has no net velocity with respect to the surface F. This scanning action makes the total time interval recorded during one sweep independent of the cell length.

Resolution

With the ultrasonic light modulator it is possible to obtain tens of thousands of resolution elements in a single scan line. In aerial photography, the only limitations are photographic, specifically, the resolution of the photographic material and the optical components.

Resolution in time is limited by the bandwidth. However, information bandwidths close to 20 mc have been obtained with this device. Furthermore, there is no halation effect analogous to that in the crt. As a result, dynamic ranges of several hundred to one have been obtained in field models, and in laboratory models considerably higher ratios are realizable.

The linearity of the ultrasonic light modulator is shown in Fig. 2. The diffraction efficiency is plotted as a function of input voltage for an ultrasonic light modulator arrangement used in video recording. Diffraction efficiency is defined as that percentage of the light entering the system at D_1 (Fig. 1) which goes into the formation of the final image. It can be seen from Fig. 2 that

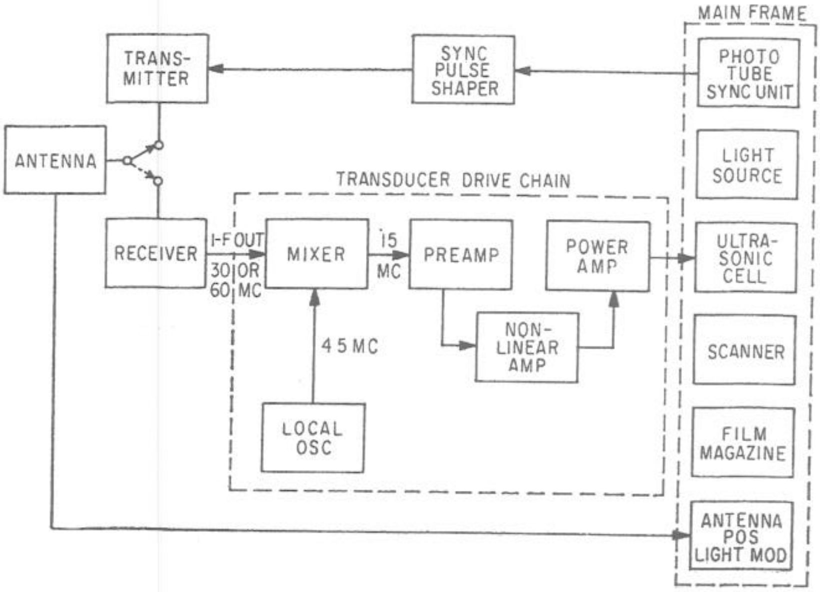


FIG. 3—Block diagram of a typical radar strip map recorder using the ultrasonic cell. The antenna position light modulator records antenna position on the film

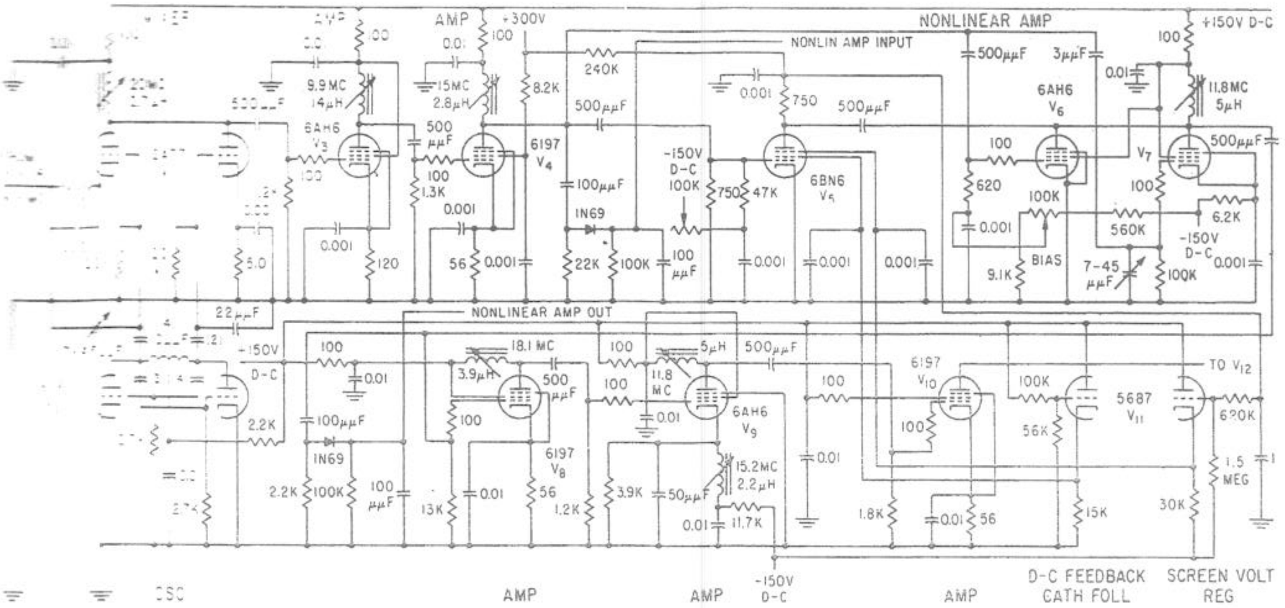


FIG. 4—Circuit schematic of a portion of the transducer drive chain. Linearity correction is made by adjustment of the gains of V_5 and V_6. Stage V_5 amplifies only low-level signals while V_6 amplifies only high-level inputs

When 125 v rms is applied to the transducer, the diffraction efficiency approaches 70 percent. The portion of the curve between points *A* and *B*, corresponding to 9 and 58-percent diffraction efficiency, respectively, is linear within 2 percent.

Video Recording

The simplest application of the ultrasonic light modulator is in video recording. If in Fig. 1, photographic strip film is placed in the plane of *F* and driven so that during the period of a single scan the film moves the width of a single scan line, the film is filled with transverse scan lines, density modulated in accordance with the input signal amplitude. To start the second scan immediately after completion of the first scan, a mirrored polygonal prism is used for the reflector *P*.

Another recording application for this device, is in radar strip mapping. The first ultrasonic light modulator recorder, sponsored by WADC (ARL) was built for that purpose. The system used is that shown in Fig. 1, but the film is driven with a velocity proportional to the aircraft velocity and successive scans of the reflector *P* are synchronized with the radar pulse transmission, so that a strip map recording results.

A block diagram of a representative system is shown in Fig. 3. A radar recorder which is to work with several radar systems is illustrated. The radar i-f, either 30 mc or 60 mc, is mixed with a 45-mc local oscillator. The resulting 15-mc carrier is amplified further, linearized to compensate for nonlinearities in the ultrasonic diffraction effect and the photographic emulsion and then applied to the ultrasonic cell located on the main frame.

An antenna position light modulator, which records a density-modulated track at the edge of the film in accordance with antenna position, is required because the radar sweeps are recorded next to each other in strip-map fashion, though they are derived either from a ppi or sector-scan radar.

Because of its relatively high inertia, it is more convenient to permit the scanner to trigger the radar transmitter than to have the radar transmitter control the scanner. A simple method uses light from an illuminated slit, reflected from the scanner and picked up by a phototube. With this method trigger accuracies better than 5 millimicrosec have been obtained.

Transducer Drive Chain

Schematics of the transducer drive chain are shown in Figs. 4 and 5. Tube V_1 is the mixer, V_2 the local oscillator, V_3 and V_4 the preamplifier. The nonlinear amplifier comprises V_5, V_6 and V_7. Tube V_5 amplifies only low-level signals and V_6 only high-level signals so that

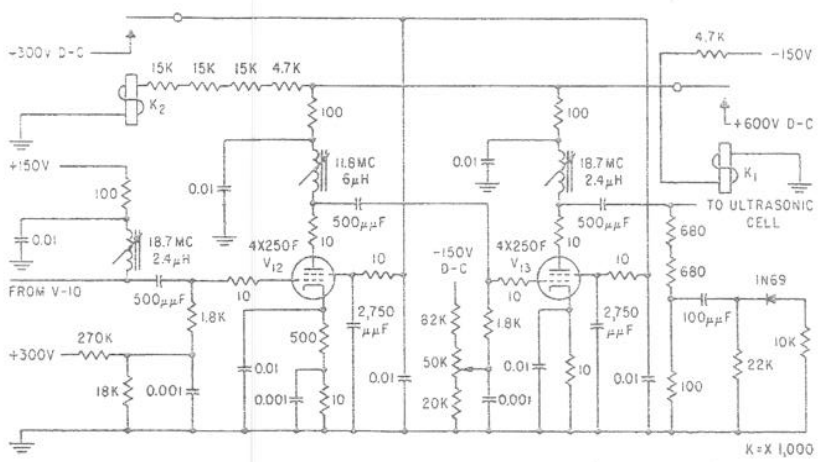


FIG. 5—Schematic of final power stages of the transducer drive chain. Relays K_1 and K_2 protect the circuit in case of bias or plate supply failure

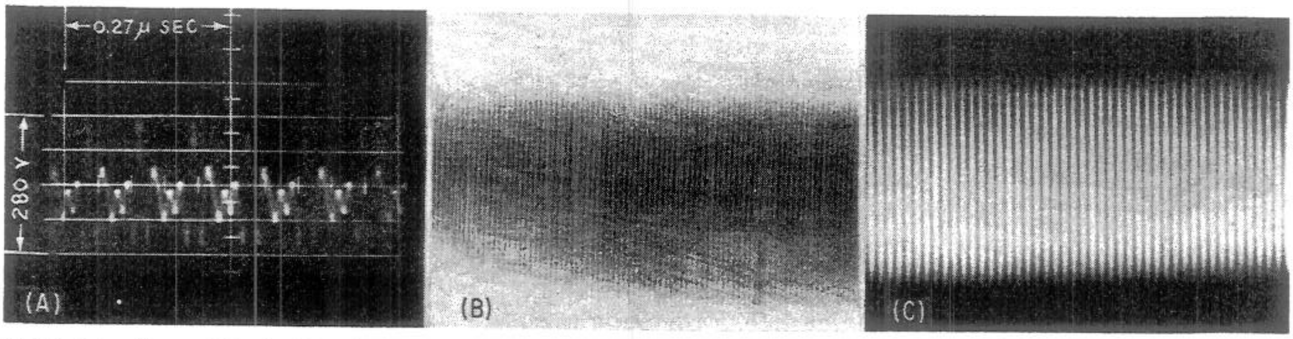


FIG. 6—Recordings attained with a high resolution radar display unit. Input signal (A) at 11 mc produced recording (B). Each band corresponds to 25 ft of range. Higher contrast is achieved with a cleaner test signal. Photo (C) represents recordings of 0.1-μsec pulse train separated by gaps of 0.1-μsec duration

good linearity may be obtained by adjusting the gains and operating points of these two stages. Stages V_8 through V_{10} constitute the power amplifier stage.

Special provisions are made in this amplifier to shape its frequency response to compensate for the resonance characteristics of the ultrasonic transducer.

The problem of testing the ultrasonic light modulator recorders on the ground requires a special test signal generator. For this purpose an optical flying-spot scanner was built. In this unit the image of a pinhole is scanned across a transparency carrying a test pattern. The transmitted light, intensity modulated by the test pattern, falls on the cathode of a multiplier phototube. The output of the phototube, suitably amplified, is then applied to the radar recorder.

A ppi scan can be obtained either by rotating the film behind a stationary slit or by rotating an image of the scan line using an optical inversion system. Both methods are employed.

Radar Display

A radar display unit to work in conjunction with a high-resolution radar has been recently completed. This work was supported by the Evans Signal Laboratories. The unit displays a B-scope scan on a 16-in. square ground-glass screen. The frame scan rate is 100 per sec and the pulse repetition rate 10,000 pps. Since the frame scan is unidirectional, a second rotating mirror prism is used for this scan. The display unit resolves two objects separated by 25 ft in range. Fig. 6A shows an 11-mc signal applied to the display unit and Fig. 6B shows the resulting display. Each light and dark band corresponds to 25 ft. in range. The input signal is shown only to account for the low contrast in the displayed signal. Difficulty in suppressing the carrier between signal pulses because of the relatively high modulation frequency accounts for the low contrast. At lower frequencies, where a better test signal was available, higher contrast was obtained as shown in Fig. 6C which represents a series of 0.1-μsec pulses separated by 0.1-μsec gaps.

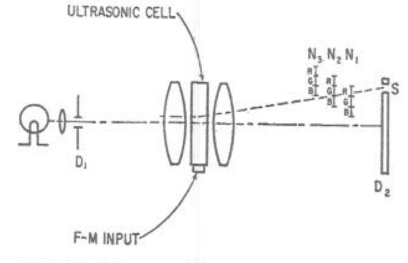


FIG. 7—Diagram illustrates how diffraction grating effect of ultrasonic cell makes color modulation possible

Slant Range Distortion

Radar maps points with a separation proportional to the difference between their distances from the antenna and not proportional to their separation in space. Consequently, recordings taken at high altitudes suffer from what is known as slant range distortion. In conventional radar indicators this is compensated for by using a hyperbolic sweep. For the ultrasonic radar recorder, an optical method of slant range correction is used. This method is geometrically accurate and lends itself readily to adjustment for changing aircraft altitude. The method consists of converting the strip image into a circular sector by rotation around the zero slant range point. If a strip is selected from this sector at a distance from the center proportional to the aircraft altitude, a corrected ground range display is obtained.

Color Modulation

Ultrasonic light modulation lends itself readily to color modulation of light. As pointed out earlier, the ultrasonic cell is essentially a diffraction grating which separates the incident light into its spectral components. The image of a narrow slit at D_1 (Fig. 1) appears drawn out to a full spectrum in each diffraction image at D_2. If one color is now selected from the spectrum, the cell image appears in that color.

The spectrum appearing under N_1 in Fig. 7 is shown in the position it assumes with frequency N_1 applied to the transducer. In that position, the red portion of the spectrum is passed by slit S. When the frequency is increased to N_2, the spectrum moves away from the optical axis, so that only the green light passes. A further increase in frequency results in passing of only blue light. Thus, the color of the cell image is varied by frequency-modulating the carrier signal applied to the cell, just as the brightness of the cell image is varied by amplitude modulations. Thus continuous change in hue is possible.

This effectively adds another dimension to the recording which may be used to record additional information contained in the input signal. For example, a combined radar display may be devised featuring elevation data in color.